

Improving Surface Flux Parameterizations in the NRL Coupled Ocean/Atmosphere Mesoscale Prediction System

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LONG-TERM GOAL

The long-term goal is to understand the physical processes that critically regulate the coupling between the oceanic and atmospheric boundary layers and develop advanced parameterizations of this interaction for a new generation of coupled ocean-atmosphere models.

OBJECTIVES

The objective of this research is to improve the surface flux and boundary layer turbulence parameterization in COAMPSTM for low- and high-wind events over the ocean in the context of air-sea interaction. Special emphasis will be placed on flux parameterizations in both low- and high-wind regimes in collaboration with the CBLAST Defense Research Initiative (Coupled Boundary Layer Layers/Air-Sea Transfer) community.

APPROACH

There are two complementary and strongly interacted components in our study: modeling and observational efforts. Our first approach is to use COAMPS[®] as a tool in understanding the physical processes and developing new parameterizations for the surface and boundary layer turbulence mixing. We provide real-time COAMPS weather forecasts for each intensive observational period of the CBLAST-Hurricane and CBLAST-Low field experiments, and therefore establish a focused model dataset, which can be used, with the measurements, to evaluate the model physics and investigate the impacts of the interaction on the mesoscale weather prediction. We also use various single column versions of COAMPS and experiment data to study the detailed turbulence processes, and develop new parameterizations. The second approach is the observational study that included measurements in the boundary layer and upper air at the CBLAST Nantucket site. These measurements are critical in the evaluation of the COAMPS forecast and development of the new parameterizations. They also provide a valuable data source for the process study of the air-sea interaction in that area.

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WORK COMPLETED

1. Evaluate new roughness length formulations under low wind condition (Collaborate with Dean Vickers and Larry Mahrt of Oregon State University)

Surface roughness lengths for momentum, sensible heat and latent turbulent transfer are crucial parameters for modeling the surface fluxes. Recently, Vickers and Mahrt (2006) developed a new set of formulations for the roughness lengths. In this study, these formulations of surface roughness lengths are evaluated using COAMPS surface flux scheme and turbulence flux data from aircraft measurements in CBLAST and SHOWEX field experiment. An off-line COAMPS surface flux model is used to calculate surface momentum, sensible and latent heat fluxes with the input of 10-m level mean wind speed, temperature, and water vapor mixing ratio. Two COAMPS surface flux calculations are performed; the first uses the existing roughness lengths, the second uses the new formulations. Then, the COAMPS derived fluxes from both calculations are compared with those computed from the turbulence data using eddy correlation method. The results are shown in Fig. 1.

2. Explore sea spray impact on hurricane intensity in COAMPS (Collaborate with Yi Jin of NRL)

Sea spray may have important impact on the hurricane development. To study the impact of sea spray on the hurricane intensity forecast, we implemented the latest version of sea spray parameterization of C. Fairall (2007), in which the surface layer profile feedback mechanism is refined. The strength coefficient of the spray scheme is adjustable; it is set to be 0.5 and 1 with the former being closer to previous estimates. A high-resolution COAMPS (27-9-3 km grid spacing for 3 nested grids) is performed to simulate Katrina (2005). The COAMPS results are compared with observations.

3. Investigate the formation mechanism for strong and small-scale SST variability over the New English Shelf (Collaborate with Paul Martin of NRL SSC)

Strong and small-scale SST variability (6°C over 5-10km) over the New English Shelf and corresponding variabilities of air temperature and wind were observed in CBLAST-Low field experiment in August 2003. To investigate the formation mechanism for this strong and small-scale SST variability, the Navy's Coastal Ocean Model (NCOM) was set to run with a very high resolution (200 m grid spacing) setting. Since there were energetic tidal effects on the New English Shelf, tidal forcings with both elevation and transports for eight tidal constituents of K1, O1, P1, Q1, K2, M2, N2 and S2 were included and superimposed on nontidal lateral boundary conditions, which were from the $1/8^{\circ}$ global NCOM real-time nowcast/forecast. The tidal forcings were generated from the global tidal database that developed at Oregon State University. The model bathymetry was produced from a 3-arc-second Coastal Relief Model developed by the NOAA's National Geophysical Data Center (NGDC) (Divins and Metzger, 2003). COAMPS hourly surface forecast fields from the innermost grid with horizontal resolution of 3 km were used for the atmospheric forcing. The simulated results from NCOM were studied and compared with CBLAST-Low aircraft observation.

4. Analyses of sea breeze circulation of boundary layer turbulence transition using Nantucket measurements

Rapid transition of boundary layer turbulence and vertical structure was captured by measurements at Nantucket island during the 2003 CBLAST campaign. This case was studied extensively to understand the adjustment of mean and turbulent properties at the presence of abrupt changes in mesoscale

forcing such as the passage of sea breeze front. In FY07, we focused on understanding the mesoscale environment that resulted in the rapid transition of boundary layer structure using high resolution COAMPS simulations. In order to examine the rapid transition, we used COAMPS results outputted at 10 minutes interval. The results are compared against measurements from the Nantucket tower as well as other CBLAST locations (MVCO and moorings).

RESULTS

1. Evaluate new roughness length formulations under low wind condition

The comparison shows that the new roughness formulation significantly improves latent heat flux computed from COAMPS. The new formulation also leads to moderate improvement to momentum and heat flux. The reduction in bias between modeled and observed fluxes is greatest for latent heat, momentum and sensible heat, respectively. The mean values of the existing (modified) model prediction minus the observed is 29 (-9) Wm^{-2} for latent, 0.03 (0.01) Nm^{-2} for momentum and 7 (3) W m^{-2} for sensible heat.

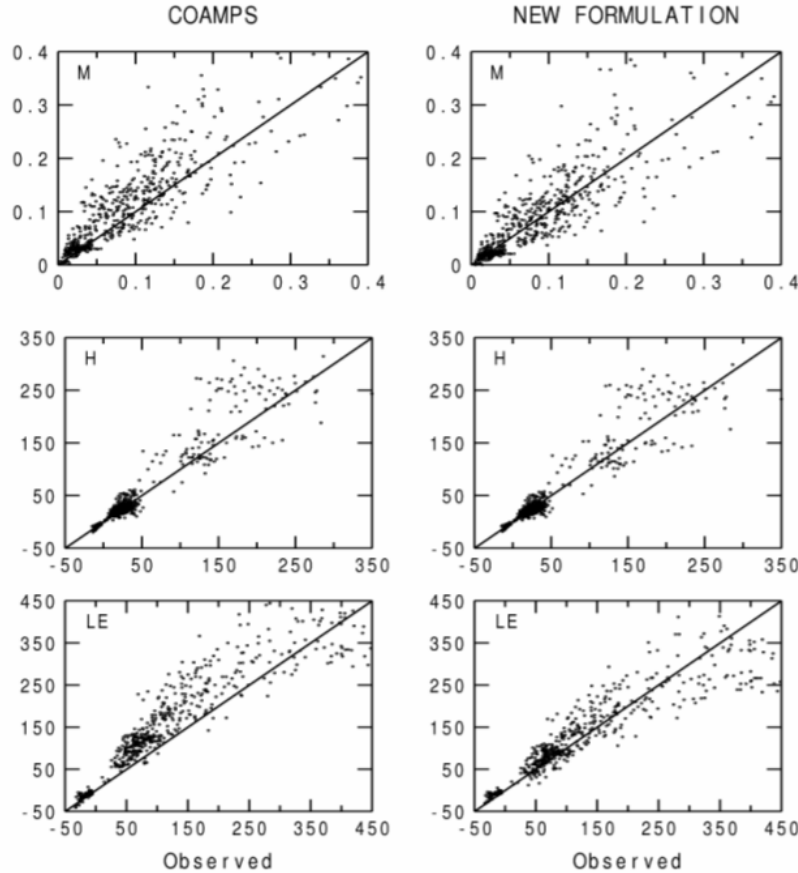


Fig. 1. Comparison of modeled fluxes (y-axes) with observed fluxes (x-axes) for the combined CBLAST and SHOWEX data. Top row is for momentum (M) (N m^{-2}); the middle for sensible heat (H) (Wm^{-2}); and the bottom for latent heat (LE) (W m^{-2}). Left column gives original COAMPS surface model results; right column gives COAMPS with new roughness formulation.

2. Explore sea spray impact on hurricane intensity in COAMPS

The ratio of surface enthalpy transfer and drag coefficient, C_k/C_D , increases with sea spray intensity due to more entropy flux going into atmosphere. Because of the increase in moisture and entropy flux by sea spray, the storm becomes stronger (moderately) as shown in right figure. Solid lines are for minimum SLP and dashed lines are for maximum wind speed. It is seen that the minimum SLP decreases by 8 mb, the wind speed increases by about 5 m/s. These changes are rather moderate. The droplet evaporation produced by sea spray also results in cooling in the surface layer, i.e. negative sensible heat flux (not shown here), which stabilizes the boundary layer and tends to reduce the storm intensity. This negative feedback of sea spray is also clear from our simulations (not shown here), which is a reason why the sea spray only moderately increases the hurricane intensity.

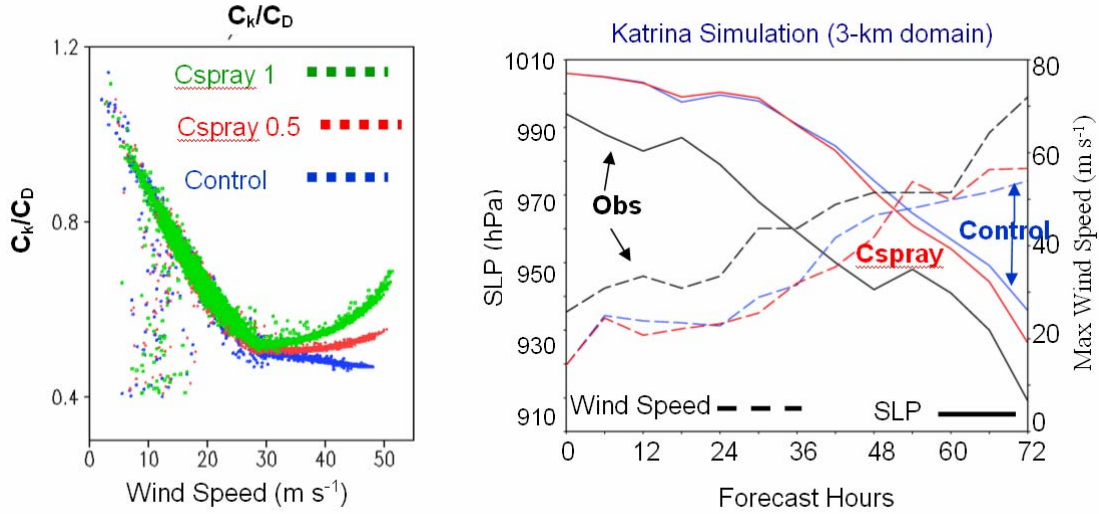


Fig. 2. Impact of sea spray parameterization in COAMPS. Left: C_k/C_D calculated from three simulations; Right: Minimum sea-level pressure and Maximum wind speed from three simulations. *Cspray 1* (green) represents the simulation in which the spray source function coefficient is set 1; *Cspray 0.5* (red) the coefficient is set 0.5; and *Control* (blue) represents the simulation without sea spray.

3. Investigate the formation mechanism for strong and small-scale SST variability over the New English Shelf

Aircraft observation in CBLAST–Low field experiment showed a very strong and small-scale SST variability (6°C over 10km) in August 2003 (Fig. 3a). Simulation indicated that high tide energies over the Nantucket Shoals with the atmospheric forcing were responsible for this variability. As shown on Fig. 3b, when NCOM simulation with both of atmospheric forcing and tidal forcing, a cold water band intruded from the cold SST over the Nantucket Shoals to the south of Martha’s Vineyard. This cold water intrusion significantly modulates the spatial distribution of SST and induces strong SST variability. On the other hand, when the simulation is with tidal forcing only, colder SST and wider area of cold SST are obtained (Fig. 3c). Much cooler water covered Nantucket Sound and Muskeget Channel and connected with the cold water in the south of Martha’s vineyard. Without the tidal forcing, there is

no cold SST pool over the Nantucket Shoals and then no significant cold water intrusion (Fig. 3d). The results indicate that the tidal forcing is essential for the tidal mixing and the generation of cold SST over the Nantucket Shoals; and the atmospheric forcing can modulate the vigorous tidal mixing and lead the cold water intrusion from the east to the west.

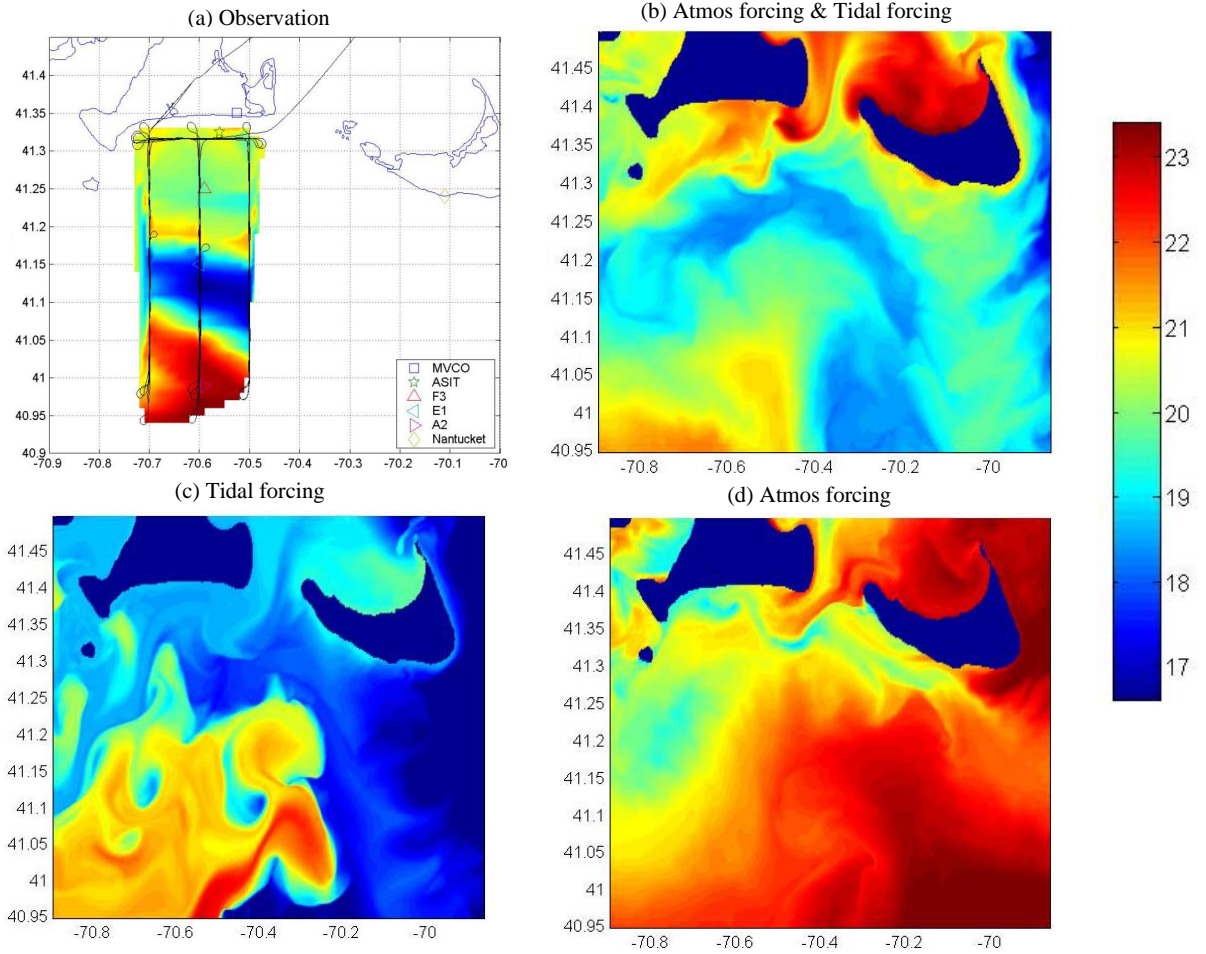


Fig. 3. Sea surface temperature from (a) aircraft observation, and NCOM simulations with (b) atmospheric forcing and tidal forcing, (c) tidal forcing only, and (d) atmospheric forcing only.

4. Analyses of sea breeze circulation of boundary layer turbulence transition using Nantucket measurements

COAMPS simulations showed local sea breeze development as a result of the presence of the islands of Martha Vineyard and Nantucket. The presence of such local sea breeze is seen in Fig. 4a when the local sea breeze (westerly flow) front reached the measurement site on Nantucket. Because of the shape of the island, the location of the sea breeze front is highly variable along the south coast of Nantucket. The island sea breeze events are much weaker and delayed in time compared with that along the New England coast (Fig. 4b). In general, COAMPS predicts the wind direction change associated with the onset of the local sea breeze circulation reproducing the feature of the sea breeze transition. However, the transition timing appears slightly later in COAMPS (about an hour) than the observa-

tions show. Moreover, the observed sharp changes in air temperature and humidity at the time of transition are not well reproduced, with COAMPS results showing a rather smooth temporal change in these mean properties.

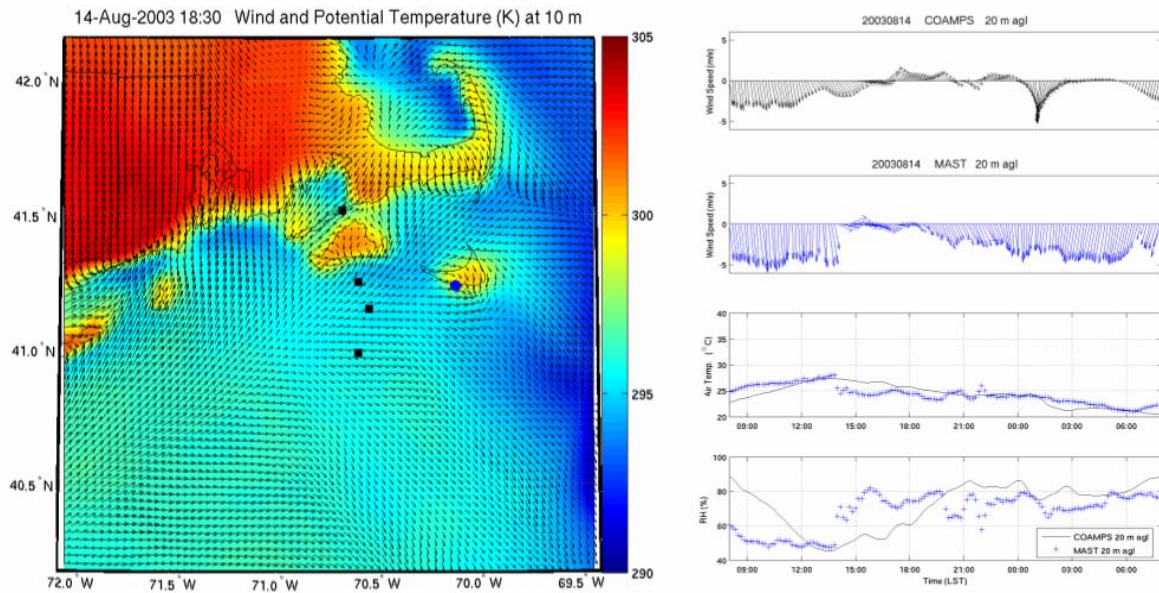


Fig. 4. (a) COAMPS wind vector and potential temperature distribution over the wider CBLAST area. The blue dot denotes the CBLAST Nantucket site and black squares denote the locations of moorings off the coast of Martha's Vineyard Islands. (b) Comparisons of COAMPS results with the Nantucket 20 m mast measurements.

IMPACT/APPLICATIONS

The turbulent momentum, heat, moisture exchange between ocean and atmosphere at their interface represents the most important interaction between these two fluids. Correct modeling of these transfer coefficients is essential for mesoscale model prediction capability. Current studies have improved the surface flux parameterization in COAMPS at both high- and low-wind conditions. The continued research on this issue will significantly enhance COAMPS prediction capability for both atmosphere and oceans.

TRANSITIONS

The new parameterization of the drag and moisture transfer coefficients under high winds developed in connection with this project were transitioned to FNMOC in June 2007.

RELATED PROJECTS

Related projects are 6.2 Next Generation COAMPS and 6.2 Coupled TC. Related project at NPS is Award # N0001405WR20338 for COAMPS surface flux and boundary layer parameterization study evaluation using aircraft measurements.

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